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Network lifetime maximization in wireless sensor network with multiple sink nodes

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This work investigates the performance statistics of event based data delivery model for Agro-ecological Sensor Network with multiple sink nodes. Agro-ecological sensors improve the task of farm management and helps in reduction of environmental as well as economical production cost. Due to the limited battery power of the sensor nodes it becomes necessary to design the architecture and operation of the wireless sensor network so as to optimize the energy consumption. It is crucial for the lifetime of the individual sensor nodes and finally for the overall network lifetime. Traffic and performance management in these resource constraint sensor networks depends on network design issues like, sensor deployment, sensor activity schedule, sink location problem and routing mechanism. Energy efficient multi path routing mechanism is the backbone of this study. It is a sink initiated route discovery process with the location information of the source node already known to the sink nodes. Carried out simulation work compares the performance of single sink and multi sink networking approaches.

INTRODUCTION

A sensor node in wireless sensor network (WSN) senses the environment, acquires information within its sensing range and transmits it to the information gateway [1-4]. Reliable transmission of the detected event to a sink node and finally to the central station is based on collective information sharing from the source node via several intermediate nodes to the sink node(s). The basic architecture of an agro-ecological sensor node is shown in Figure-1. Traffic and performance management in such networks depends on network design issues like, sensor node deployment, sensor activity schedule, sink location problem and routing mechanism [5]. Several reported studies try to make energy usage more efficient through optimal determination of these network design issues [6].

Energy efficiency, scalability, reliability and robustness are the most significant design goals for WSN networks [7]. In resource constraint WSN networks, energy consumption is dominated by the transmission and reception of the data packets. However, a small amount of energy is dissipated in the process of sensing and computation [8]. The overall energy dissipation, E_{Total} for a node in the network is expressed as

$$E_{Total} = E_{Comm} + E_{Comp} + E_{Sens} + E_{Sleep} \qquad (1)$$

Where, E_{Comm} is energy consumption because of the transmission and reception of data packets. E_{Comp} is energy required for data computation, E_{Sens} is the energy dissipated during the sensing operation and E_{Sleep} is the power dissipated during sleep state. It also includes energy losses during sleep and idle mode operations. It is observed that E_{Comp}, E_{Sens} and E_{Sleep} are negligible when compared to the energy levels of $E_{Comm.}$ therefore, energy efficient light weight communication protocols are required to reduce the redundancy in data transmission [9].

Proposed multipath routing protocol is based on sink initiated route discovery process. In this mechanism, node location information of the source node is known to the sink nodes. There are two types of the nodes; primary nodes and the alternate nodes. During the route discovery process, one primary and some other alternate routes are built and nodes except in the primary path are put into the sleep mode to conserve the energy and to generate a collision free path. The primary path is selected for the transmission of the data packets and if the route is disrupted, the next best alternate route having the lowest communication cost among all alternate paths is selected [9].

This work highlights network lifetime maximization of multi sink wireless sensor network deployed for agro-ecological applications [10]. The integration of agroecological information is needed for the effective management of farm resources and improved economic viability of farm products [11]. Farm management information system, involved in this task, is defined as a network of different components aiming to acquire, format and disseminate operational information related to the environmental and agricultural variables [12].

Ecological farming, conservation of natural resources and ecological restoration are the major concerns highlighted in National Policy for Farmers [13]. Sensor based information systems can significantly contribute to these objectives [14]-[17]. Mostly, farmers need information about weather, soil moisture, soil nutrients and crop health for effective management crop and farm resources. These are illustrated in Table 1.

The approach under investigation is helpful in reduction of network contentions and total number of data packets transmitted inside the network. It also takes care for distributed control over the network in

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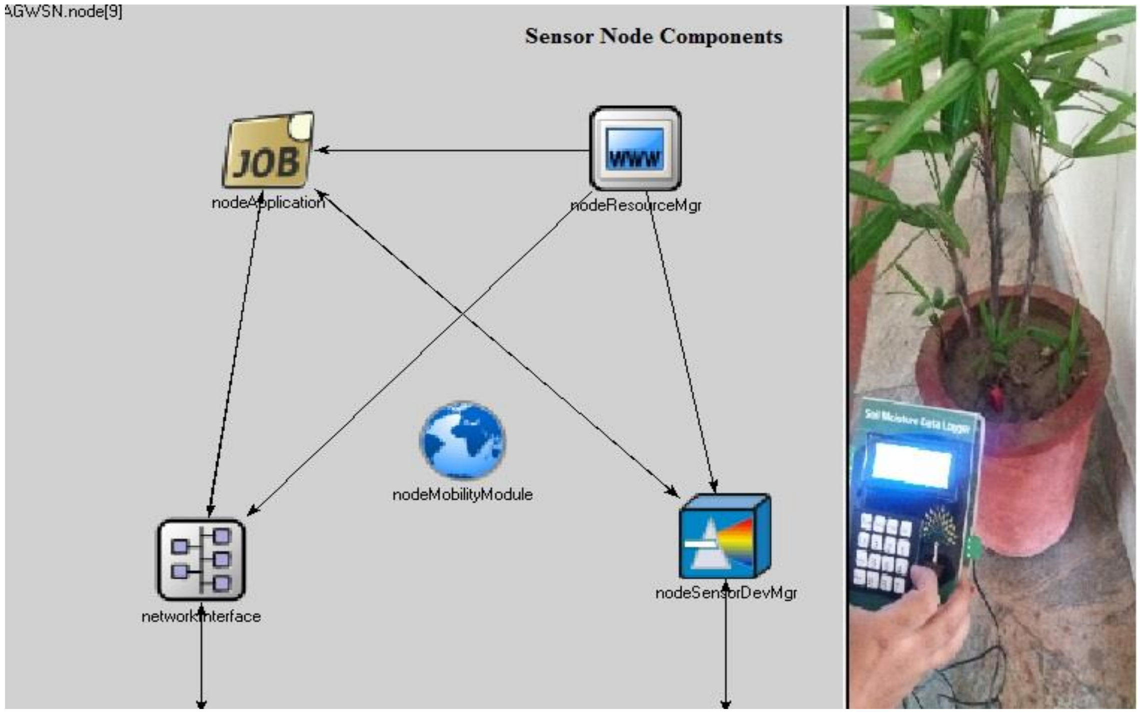

Figure 1 Sensor node architecture of an agro-ecological sensor

Table 1 Agro-ecological information Sensors

Sensor Application	Parameter
Climate Data	Air Temperature
	Atmospheric Pressure
	Humidity
	Precipitation
	Solar Radiation
Soil Data	Soil Moisture
	Soil Temperature
	Soil pH
	Micro Nutrients
Crop Data	Leaf Wetness
	Crop Health

sleep mode, battery level and Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). Rest of the paper is organized as follows; section 2 presents a summary of related work followed by proposed methods in section 3. Section 4 describes the simulation results and section 5 concludes the entire discussion with the targeted future works.

RELATED WORK

Network lifetime is an important performance metrics for battery powered WSN Networks. Transmission power control is a well established method to minimize the energy consumption during data transmission in order to extend the overall network lifetime [8]. The network lifetime is described as the time of the first loss of coverage or connectivity in the network [2].

The system level power awareness such as dynamic voltage scaling, low duty cycle, system partitioning and energy aware MAC protocols are energy efficient techniques at physical layer and medium access control layers [18]. At the network layer, the main goal is to find ways for energy efficient route set-up and reliable transmission of data packets so that the lifetime of the network is maximised [19]. Classification of various routing protocols is presented in Table 2. Here, the protocols are classified on the basis of location awareness, network layering, energy awareness, data centricity, multipath propagation, mobility, QoS support, in-network processing and support for various heterogeneous sensor nodes.

Uneven load distribution leads to the premature energy exhaustion on critical router of the network. Generally these nodes are closer to the sink. This problem is often referred as energy-hole problem. (Keskine) highlighted role of four major design issues: deployment of sensor

Table 2 Classification of Routing Protocols for Wireless Sensor Networks

Classification Criteria	Protocols Description
Location Awareness	GAF, GEAR, Span, TBF, GeRaF, MECN, PEGASIS, Quorum and home agent - based information dissemination, TTDD, SEAD, CADR, CHR.
Network Layering	RPL, GAF, LEACH, HEAD, PEGASIS, TEEN, APTEEN, Cougar, EAD, TTDD, SEAD, IDSQ, CADR.
Energy Awareness	EAP, EAD, BLM, BEAR, MECN, SMECN, LEACH, PEGASIS, TEEN, APTEEN, SPIN, TTDD, SEAD, Energy - delay trade off, Energy - robustness trade off.
Data Centricity	D3, BLM, GEAR, TEEN, APTEEN, SPIN, Directed diffusion, Rumor routing, Cougar, ACQUIRE, EAD.
Multipath Based	TBF, SPIN, BLM, Directed diffusion, Braided multipath, N - to - 1 multipath discovery.
Multi Sink Routing	BLM, RPL, MUSTER, EMCA, GBR-G, GBR-C.
Mobility Based	GAF, TBF, MECN, SMECN, Joint mobility and routing, Data MULEs, TDD, SEAD.
Quality-of–Service Based	BLM, QMOR, PEGASIS, TEEN, APTEEN, SPIN, Directed diffusion, N - to - 1 multipath discovery, Data MULEs, TTDD, IDSQ, CADR.
In -Network Processing	RPL, LEACH, HEAD, PEGASIS, TEEN, APTEEN, SPIN, Directed diffusion, Rumor routing, Cougar, ACQUIRE, EAD, TDD, CHR.
Heterogeneity Based	RPL, BLM, Data MULEs, IDSQ, CADR, CHR.

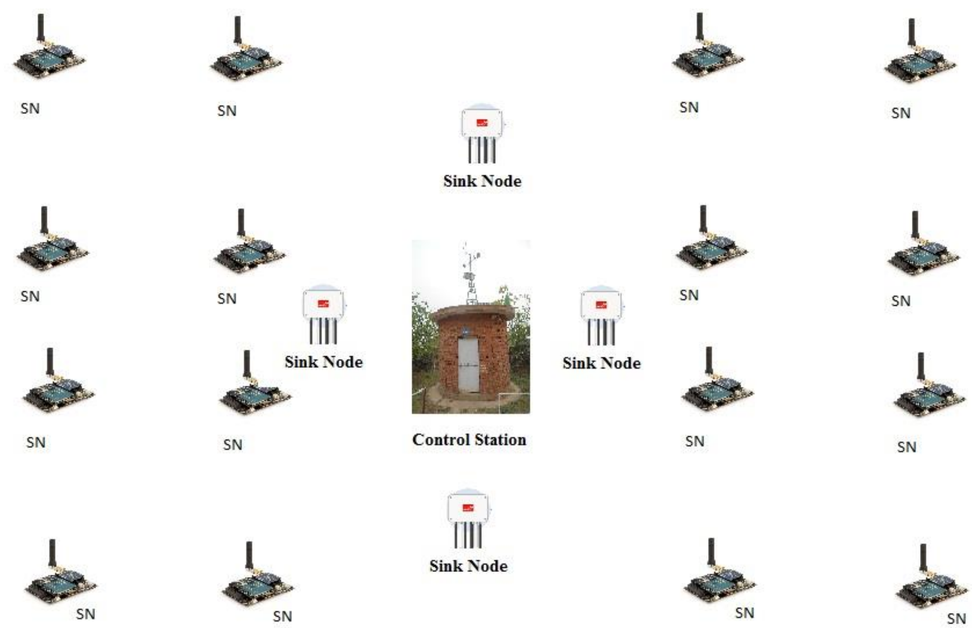

Figure 2 Field deployment of agro-ecological sensor nodes

nodes, node activity schedule, sink location and routing mechanism to improve the energy efficiency [19]. Their study considers the cost of sink node, in terms of lifetime hours.

Management of battery resources for prolong network lifetime is the major point of discussion in the research paper of (Liu, et. al.). In their work authors have described dynamic lifetime estimation technique for better utilization of network resources. Energy aware routing protocol is described in by in [20]. A novel traffic aware routing protocol is discussed by (Tan and Kim). It proposed a new routing approach for balancing the traffic load among all nodes using gradient search. Data delivery path sharing is also an important point highlighted in this work [10]. Relationship between clustering algorithms and energy efficiency is investigated by (Xu, et. al.). Energy balancing sink node deployment and network life time are the prime concern for this research work specially targeted for self organizing, infrastructure less and fault tolerant sensor networks [21].

The network performance was evaluated in terms of packet delivery ratio, reduced overall delay and energy consumption by (Jain, et. al.). Their work highlighted the significance of multiple sink for reducing the number of packet transmission [22] in the network and its impact on network lifetime. Restructuring of neighbour nodes for the sink nodes is the key design issue for energy balancing and the energy-hole problem.

METHODS

Proposed multipath routing protocol is based on sink initiated route discovery process. In this mechanism, node location information of the source node is already known to the sink node(s). There are two types of paths; primary paths and the alternate paths. During the route discovery process, one primary and some other alternate routes are built and nodes

except in the primary path are put into the sleep mode to conserve the energy and to generate a collision free path. The primary path is selected for the transmission of the data packets and if the route is disrupted, the next best alternate route having the lowest communication link cost among all alternate paths is selected [9].

Some important points investigated in this work are highlighted as follows

(1) Sensor nodes are deployed in a grid topology and then they are fixed at their respective positions.

(2) Data packets are forwarded to the sink nodes using multipath approach having minimum communication cost.

(3) There are two types of the nodes; primary nodes and the alternate nodes. During the route discovery process, one primary and some other alternate routes are built and nodes except in the primary path are put into the sleep mode to conserve the energy and to generate a collision free path.

(4) The primary path is selected for the transmission of the data packets and if the route is disrupted, the next best alternate route having the lowest communication cost among all alternate paths is selected.

(5) The nature of the selected agro-ecological sensor network is heterogeneous and sinks have more battery power than the sensing nodes. The sink nodes have additional computational capabilities as well.

Ideally, only one message should be received by the sink for every message sent by the source [9], i.e., a redundancy of 1. For multiple paths from the source to the sink, the redundancy R is calculated using

$$R= \frac{1}{d(n1)} \sum_{i=1}^{N} s(ni) \qquad (2)$$

Where *ni* denotes the *i*th node, with *n*1 the source node, *s*(*ni*) the total number of data messages sent by node *i*, and *d*(*n*1) represents the depth or the rank of the source node.

Fair and even distribution of network traffic among all sink nodes reduces the number of hop counts and hence the transmission cost. Here, connectivity of a sensor node to a sink node, on the basis of communication link cost is considered. In this approach each node constructs a routing metrics to a unique sink node. Energy link cost [2] of a sensor node is given as

$$\Delta E_{ij} = P_{TX} * \Delta T, \qquad (3)$$

Where P_{TX}: Transmission Power

ΔT: Estimated transmission time, where

$$\Delta T = S/BR*P \qquad (4)$$

Where, S: Packet size

BR: transmission rate

P: Probability of successful transmission

During the process of route selection, critical battery power nodes are escaped. The communication link cost [2] of the entire path is given as

$$C(X) = \sum_{i=0}^{k} |N(vi)| \qquad (5)$$

Where, N(vi): communication cost of the link (v1, v2)

Given path X = {e0,e1,e2,……..ek}

$$ei = (vi, vi+1) \qquad (6)$$

For Validation of proposed approach multiple iterations of the simulations are performed considering the case of single sink communication model and then multi sink communication. For this purpose, a network of 25 sensor nodes is selected. In case of multi sink architecture 4 sink nodes are deployed near the control station. Five weather station sensors are also placed near this control station and rest of other 16 agricultural sensors are deployed in the grid topology, as illustrated in Figure 2. These nodes communicate using the Chipcon CC2420 radio transceiver [23]. This radio transceiver works on IEEE 802.15.4/ZigBee communication protocol standard [24].

Farm management information system, involved in this task, is defined as a network of different components aiming to acquire, format and disseminate operational information related to the environmental and agricultural variables [12]. Each sensor node is having five modules; network interface module, node mobility module, node sensor device manager, node resource manager and node application module. Network interface module is further divided into network sub-module, medium access control (MAC) sub-module and radio module. The physical layer of this network is implemented by the radio standard of the Chipcon CC2420 used as transceiver of portable data logger of M/s Advance Tech India Private Limited [25]. Medium access control is taken care by CSMA-CA protocol and network protocol supported in our set up is resource aware multipath routing protocol [26].

RESULTS

All the sensor nodes in the network periodically send data packets to the sink nodes. Each data packet has a unique packet ID to track the number of lost packets. It contains information about the node which includes rank, energy consumption, preferred parent nodes, communication link cost for the respective parent nodes etc. This information in the data packets help in determination of energy consumption and average number of hops to the designated sink.

Because of limited battery power and computational capabilities of sensor nodes and low capacity of individual paths, recently, multipath routing mechanism is broadly utilized to increase the network capacity under high traffic conditions. Simulation set up for the described case study shown in Figure-3. Energy efficiency is the prime concern of our study. However, other network performance metrics like packet delivery ratio and average packet latency are also taken into the account before drawing the final conclusions.

This section illustrates the influence of the communication distance from the sensor to the nearest sink on the packet delivery ratio, latency and consumed energy. The simulation parameters, expressed in the Table 3 are used for the validation purpose. In case of single sink, level of energy consumption is quite higher for certain nodes but in multi sink a better balance is observed and energy consumption is significantly reduced for these nodes. In multi sink wireless sensor network, total energy consumption was reported as 16.976 J and for single sink it was recorded as 19.502 J, for the entire duration of simulation. Multi sink approach improved overall energy efficiency by 12.95%. It also improved energy balancing, as shown in Figure 4, among all nodes.

The information obtained from the simulation log file helps in calculation of average delay for all the nodes, however this network is modeled as a delay tolerant network. Average packet delay is calculated as

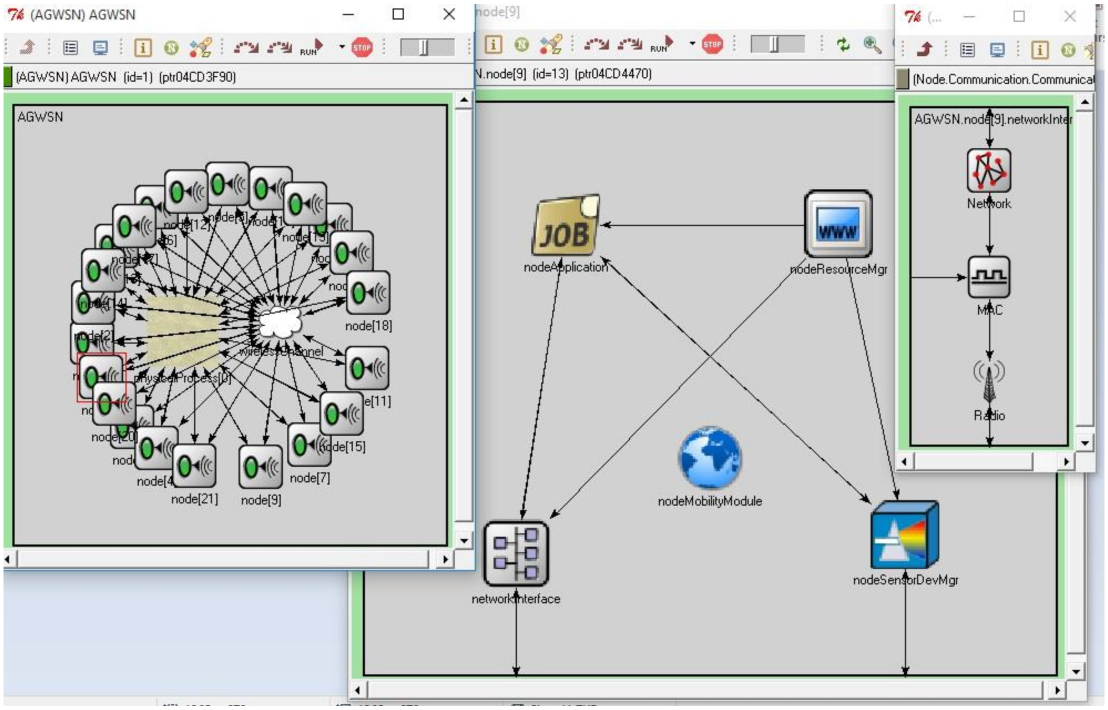

Figure 3 Simulation set up for agro-ecological sensor network

Table 3 General Simulation Parameters

Parameter	Value
Field Area	100 m x 100 m
Traffic Type	Periodic
No. of Sink Nodes	1 and 4
Sensor Nodes	21
initial Energy	18720 J (AA Battery)
Energy Calculation Interval	1000 ms
Network Interface Radio	CC 2420
MAC Module Name	IEEE 802.15.4
Climate Data Sensors	5
Soil Data Sensor	12
Crop Data sensors	4
Simulation Time	60 sec

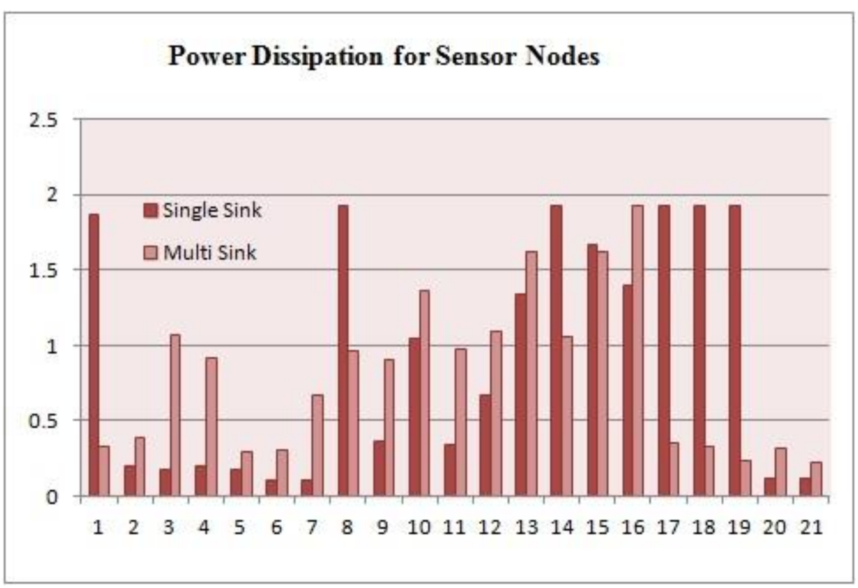

Figure 4 Energy consumption for sensor nodes deployed in the sensor field

Table 4 Simulation Results

Parameters	WSN with Single Sink	WSN with Multi Sink
Total Consumed Energy	19.502 J	16.976 J
Average Packet Latency	317.36 ms	376.49 ms
Average Packet Delivery *Ratio*	84.31%	84-24%

$$Delay\_avg = \sum_{i=1}^{n} \frac{di}{n} \qquad (6)$$

Where di is the delay for the ith packet and n is the total number of packets received. It is reported that the average delay for the single sink is slightly lower than multi sink network. Average delay for the network with single sink is 317.36 ms while for multi sink reported value is 376.49 ms. It is reported because of higher number of queries generated from the sink nodes. However, just a small difference in average packet delivery ratio is recorded. Summary of the simulation results is presented in table 4.

DISCUSSION

As an application scenario, this article considers an agro-ecological sensor network with multiple sinks for improved reliability and overall network lifetime. The idea is to create smart and cost-effective communication framework for the farmers without need of costly infrastructure. Multipath routing mechanism is considered as an efficient approach to improve network capacity, network performance and resource utilization under heavy traffic conditions. Results obtained validates that multi sink approach saves 12.95% of energy against single sink deployment. This work highlights the role of multipath routing approach that satisfies the performance requirements for agro-ecological applications with the maximization of network lifetime. One of the conclusions that can be extracted from our study is that ZigBee is extremely useful when integrating information from the sensor nodes of different acquisition and computational capabilities. In the next Phase of our study it planned to implement physical sensors and integrate the acquired information and help farmers in making effective farm decisions.

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